PHYSICS

BOOKS - S CHAND PHYSICS (ENGLISH)

THERMAL CONDUCTION

Solved Example

1. A uniform metal rod AB 80 cm long is heated at the end A and the end B is kept in ice. The temperature of the end A is 100°C and that of the end B is 0°C. The rod is covered with wool such that there is no loss of heat from the surface of the rod. Assuming steady state find (i) the temperature gradient along the rod, (ii) the temperature at a point D distance 60 cm from the end A and (iii) the distance of the point C from the end A where the temperature is 65°C.

2. The area of a glass window is $1.2m^2$. The thickness of the glass is 2.2 mm. If the temperature outside is 36°C and the temperature inside is 26°, calculate the heat flowing into the room every hour. Thermal conductivity of glass is $0.8Wm^{-1}K^{-1}$.

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3. One of the faces of a copper cube of side 7.7 cm is maintained at 100°C and the opposite face at 30ºC. If the thermal conductivity of copper is $385 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$. Calculate the rate of heat flow through the cube?

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4. A 'thermacole' icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is $45^\circ C$, and co-efficient of thermal conductivity of thermacole is $0.01 J s^{-1} m^{-1} K^{-1}$. [Heat of fusion of water $= 335 \times 103 J kg^{-1}$]

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5. Two slabs of thickness x_1 and x_2 and thermal conductivities k_1 and k_2 are in thermal contact with each other as shown in Fig. 11.4. The temperature of their outer surfaces are T_1 and T_2 respectively.

$(T_1 > T_2)$. Find the temperature at the surface.

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6. A boiler is made of a copper plate 3 mm thick. The inner surface of the copper plate is coated with a layer of tin of thickness 0.3 mm. The surface of the plate exposed to the gas at 700°C is 150cm^2.Find the maximum amount of steam that could be produced per hour at atmospheric pressure. The coefficient of thermal conductivities of copper and tin are 397 $Wm^{-1}K^{-1}$ and $63 Wm^{-1}K^{-1}$.

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7. In an experiment to determine the thermal conductivity of copper with Searle's apparatus, 100 gm of water flowed in 4.2 minutes past the cold end of the copper bar, its initial and final temperatures being 25°C and 52°C respectively. If the temperature difference between two points in the bar 10 cm apart is 23°C and the area of cross-section of the bar is 5 cm^2, calculate the coefficient of thermal conductivity of copper. Specific heat capacity of water $4, 200\text{J kg}^{-1}\text{K}^{-1}$

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8. A bar of length 30 cm of uniform cross-section of 5 cm^2 consists of two halved AB of copper and BC of iron welded together at B.

The end A is maintained at 200ºC and the end C at 0° C and the sides are thermally insulated. Find the rate of flow of heat along the bar when the steady state is reached. Thermal conductivities are copper $378 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$ and iron 50.4 $\mathrm{Wm}^{-1} \mathrm{K}^{-1}$ (Fig. 11.12)

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9. In fig. 11.13 two metal bars of thickness x_1 and x_2 and coefficient of thermal conductivities K_1 and K_2, placed end to end. What is the coefficient of thermal conductivity of a uniform slab of thickness $x_1 + x_2$ whose conductivity is the same as that of the system of two bars ? Assume that there is no heat loss from the lateral sides.

10. A, B and C are three identical rods made of different materials and placed end-to-end as shown in Fig. 11.16. The thermal conductivity of A is twice that of B and four times that of C. The free end of A is kept at 100° and that of C is kept at 0°C. Find the temperature of the AB junction and the BC junction.

11. Calculate the rate of increment of the thickness of ice layer on a lake when thickness of ice is 10 cm and the air temperature is $-5^{\circ}C$. If thermal conductivity of ice is 0.008 cal $\mathrm{cm}^{-1}\mathrm{s}^{-1}{}^{\circ}\mathrm{C}^{-1}$, density of ice is $0.91 \times 10^{3}\mathrm{kg\,m}^{-3}$ and latent heat is 79.8 cal gm^{-1}. How long will it take the layer to become 10.1 cm ?

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12. A, B and C are three identical rods made of different materials and placed end-to-end as shown in Fig. 11.16. The thermal conductivity of A is twice that of B and four times that of C. The free end of A is kept at 100° and that of C is kept at 0°C. Find the temperature of the AB junction and the BC junction.

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13. An iron bar of uniform cross-section and length one metre is kept with its one end in contact with ice at $0^{\circ} C$ and the other end in contact with water at $100^{\circ} C$. The temperature at a certain point of the bar is $150^{\circ} C$ so that during the steady state, the quantity of ice melting is equal to that of steam produced in the same interval of time. Find the distance of the point ? [See Fig. 11.17]

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14. In Lee's disc experiment two discs are separated by gap of thickness 5 mm. The space between the discs contains a gas of thermal conductivity $3.88 \times 10^{-5} \mathrm{Wm}^{-1} \mathrm{K}^{-1}$. At the steady state the temperature, of the two sides of discs are $368 K$ and $333 K$. If the area of cross-section the slab is 25 cm^2, calculate the quantity of heat crossing the gas per second.

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Conceptual Short Answer Questions With Answers

1. Stainless steel cooking pans are preferred with an extra copper bottom. Why?

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2. At what common temperature would a block of wood and a block of metal feel equally cold or equally hot when touched?

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3. Two metal rods 1 and 2 of the same length have same temperature difference between their ends. Their thermal conductivities are K_1 and K_2 and cross-section areas A_1 and A_2 respectively. What is the required condition for the same rate of heat conduction in them?

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4. A thermal conductor is heated at one end. What is the theoretical value of its thermal conductivity in order that the other end also attains the same temperature?

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5. Pieces of glass and copper are heated to the same temperature. Why does the piece of copper feel hotter on touching?

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6. Thermal conductivity of air is less than that of felt but felt is a better heat insulator in comparison to air. Why ?

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7. Woollen clothes are worn in winter, Why?

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8. Two shirts are warmer than a single shirt of double the thickness. Why ?

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Long Answer Questions

1. Describe an experiment to determine the coefficient of thermal conductivity of a good conductor by Searle's method.

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2. Explain Lee's disc method of finding the thermal conductivity of a bad conductor.

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3. (a) Compare thermal conductivity and electrical conductivity

(b) Explain Wiedemann Franz law.

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4. (a) Discuss the heat flow through a composite slab.

(b) Derive an expression for the rate of increase of thickness of ice on a lake.

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5. Explain the term temperature gradient. The two ends of a metal bar are maintained at two different consistant temperatures. On a single graph draw sketches to show the variation of temperature along the bar when its surface is

(i) perfectly lagged and (ii) unlagged. Explain the shape of the two sketches.

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Short Answer Questions

1. What is heat transfer ? Explain conduction of heat.

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2. Define thermal conductivity. Give its S.I. unit and dimensional formula.

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3. "After the steady state, the temperature of a conductor does not rise, even though heat is supplied",. Why?

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4. When you touch a piece of metal and a piece of wood simultaneously, metal appears colder or hotter. Can wood and metal feel equally cold or hot when touched?

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5. "We supply electric current continuously to an electric heater. But the temperature of the heater remains constant after some time." Why ?

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6. The specimen is taken in the form of 'disc' in Lee's disc method to find the thermal conductivity is a bad conductor. Why?

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7. "Cooking utensils are provided with wooden handles". Why ?

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8. "Ice is packed in saw dust". Why ?

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9. "Birds swell their feathers in winter." Why?

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10. "In winter metals appear colder than wood." Why ?

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11. Is there any connection between object's feeling hot or cold and its thermal conductivity ?

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12. In what way the steady state heat flow analog to the flow of (i) an electric current and (ii) an incompressible liquid?

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13. "A blanket keeps our body warm in winter, but the same blanket can protect ice from melting". Explain how?

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14. The top of a lake is frozen. Air in contact is at - 15°C. What do you expect the maximum temperature of water (i) in contact with the lower surface of ice an (ii) at the bottom of the lake ?

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15. Two rods A and B are of equal length. Each rod has its ends at temperatures T_1 and T_2. What is the condition that will ensure equal rate of flow of heat through the rods A and B ?

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16. A composite slab is made of two parallel layers of two different materials of thermal conductivities K_1 and K_2 are of same thickness. Show that the equivalent thermal conductivity of the slab is $\frac{2K_1K_2}{K_1+K_2}$

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17. Explain the difference between 'steady state' and 'variable state' of a thermal conductor.

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18. What is the significance of Wiedmann Franz law ?

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19. Mention the two processes responsible for the conduction of heat.

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Very Short Answer Questions

1. "Insulators also contain electrons, but they are not conductors." Why ?

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2. "Water can be boiled in a paper cup". Explain how?

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3. "It is hotter at the same distance over the top of a fire than in front of it" Why ?

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4. Two bodies of different temperatures T_1 and T_2 if brought in thermal contact, do not necessarily settle to the mean temperature $(T_1 + T_2)/2$. Why?

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5. Pieces of glass and copper are heated to the same temperature. Why does the piece of copper feel hotter on touching?

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Selected Problems Taken From The Previous Years Isc Aissce Hssce Various States Boards Roorke Qns Ncert Text From Rate Of Heat Flow

1. An iron plate $10^{-5} m^2$ area, 4×10^{-3} m thick has its opposite faces maintained at 373

K and 223 K respectively. How much heat flows through the plate per second ? Thermal conductivity of iron $= 80 \text{Wm}^{-1}\text{K}^{-1}$.

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2. Calculate the rate of flow of heat through a metal sheet 0.02 m thick and area $50 \times 10^{-4} \text{m}^2$ with its two sides at 273 K and 293 K respectively. Given $K = 0.2$ cal cm $^{-1}\text{s}^{-1}\text{c}^{-1}$.

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3. Steam at 373 K is passed through a tube of radius 0.5 m and length 3m. If the thickness of the tube is 2 mm and $K = 2 \times 10^{-4}$ in C.G.S. units find the rate of loss of heat in Js^{-1}. Room temperature is $9^{\circ} C$.

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4. A cylindrical metallic rod 0.5 m long conduct heat at the rate of 50Js^{-1} when its ends are kept a $400^{\circ} C$ and $0^{\circ} C$ respectively.

Coefficient of thermal conductivity of metal is $72 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$. What is the diameter of rod?

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5. The glass windows of a room have a total area of $5m^2$ and glass thickness is 3mm. Calculate the rate at which heat escapes from the room per minute by conduction when the inside of the windows is at a temperature $15^\circ C$ and the outside temperature is $-10^\circ C$. Thermal conductivity $= 0.84 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$.

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6. Heat is flowing through two cylindrical rods of the same material. The diamters of the rods are in the ratio $1:2$ and the length in the ratio $2:1$. If the temperature difference between the ends is same then ratio of the rate of flow of heat through them will be

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1. One face of the a cube of side 0.2 m is in contact with ice and the opposite face is in contact with steam. If all other sides are well lagged, calculate the mass of ice that melts during one hour. Thermal conductivity of the metal $= 40 \text{Wm}^{-1}\text{K}^{-1}$. L.H. of fusion of ice $= 336 \text{kJ kg}^{-1}$.

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2. The opposite faces of a cubical block of iron of cross-section $4 \times 10^{-4} \text{m}^2$ are kept in contact with steam and melting ice. Calculating the amount of ice melted at the end of 5 minutes. Given $K = 0.2$ cal cm $^{-1} \text{s}^{-1} {}^\circ \text{C}^{-1}$.

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3. A copper rod of length 60 cm long and 8 mm in radius is taken and its one end is kept in boiling water and the other end in ice at $0^\circ C$. If 72 gm of ice melts in one hour with is the thermal conductivity of copper ? Latent of fusion of ice $= 336 \mathrm{KJ}/\mathrm{Kg}$.

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4. One side of an iron plate one metre square is kept at 100°C and the other side is at 0°C. The thickness of the plate is 1 cm. If all the heat conducted across the plate in one minute is used in melting ice, calculate the amount of ice so melted. Thermal conductivity of iron $= 0.162$ in C.G.S. unit L.H. of fusion of ice $= 80$ cal/gm.

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5. Two beakers, identical in all respects, but made of different materials, are filled with equal amounts of ice at $0^\circ C$. Toe ice in one beaker melts in one minute whereas that in the other beaker melts in five minutes. Find the ratio of the thermal conductivities of the material of the two beakers.

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6. A brass boiler has a base area of $0.15 \mathrm{m}^2$ and thickness is $1.0 \mathrm{cm}$. It boils water at the rate of $6.0 \mathrm{kg}/\mathrm{min}$. When placed on a gas stove. Estimate the temperature of the part of the flame in contact. With the boiler. Thermal conductivity of brass $= 109 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$

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7. Show that in a compound slab the temperature gradient in each position is inversely proportional to the thermal conductivity. [See Fig. 11.18 (a)]

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8. A slab consists of two parallel layers of iron and brass 10 cm and 10.9 cm thick and of thermal conductivities

$500 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$ and $109 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$ respectively. The area of opposite faces are $2m^2$ each and are at temperatures 373 K and 273 K. Find heat conducted per second across the slab and also the temperature of the interface.

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9. An ice box is built of wood of thickness 1.75 cm. The box has an inner lining of cork 2 cm thick. If the difference in temperature between the interior of the box and outside is 12°C, calculate the temperature of the interface between wood and cork. Thermal conductivity of wood and cork are respectively 0.25 and 0.05 in S.I. unit.

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10. Two rods A and B of same area of cross-section are joined together end to end The free end of the rod A is kept in melting ice at 300 K and free end of B rod at 400 K. The rods are of the same length. The conductivity of A is 3 times that of B. Calculate the temperature of the junction of the rods.

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11. Two identical metal rods A and B are joined end to end. The free end of A is kept at 27°C and the free end of B at 37°C. Calculate the temperature of the interface. Thermal conductivity of $A = 385 \mathrm{Wm}^{-1}\mathrm{K}^{-1}$, that of B $110 \mathrm{Wm}^{-1}\mathrm{K}^{-1}$.

12. Two flat sheets of thickness d_1 and d_2 and thermal conductivities K_1 and K_2 are joined together. If the open face of the first sheet is maintained at temperature θ_1 and the other open face of the second sheet at θ_2. Calculate the temperature of the interface of two sheets. What is the conductivity of the composite sheets ?

13. Two plates of equal area are placed in contact with each other. The thickness of the plates are 2.0 cm and 3.0 cm respectively. The outer face of first plate is at $-25^{\circ}C$ and that of second plate is at $+25^{\circ}C$. The conductivities of the plates are in the ratio $2:3$. Calculate the temperature of the common surface of the plates.

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14. Two identical sheets of metal are welded end to end as shown in Fig. 11.19. 20 J of heat flows through 0°C it in 4 cm. If the sheets are welded as shown in Fig. (b), find the time taken for the same amount of heat to flow through the sheets.

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15. Calculate the thermal conductivity of the composite rod. The two rods A and B are made of two different materials of thermal conductivities K_1 and K_2 and are welded together.

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16. A cylinder of radius r made of a material of thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius r and outer radius 2r made of a material of thermal conductivity K_2. The two ends of the combined system are maintained at two different temperatures. There is no loss of heat across the cylindrical surface and the system is in steady state. Show that the effective thermal conductivity of the system is $(K_1 + 3K_2)/4$.

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17. A wall has two layers A and B each made of different materials. (See Fig. 11.21). The layer A is 10 cm thick and B is 20 cm thick The thermal conductivity of A is thrice that of B. Using thermal equilibrium, temperature difference across the wall is $35^\circ C$. What is the temperature difference across the layer A?

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Selected Problems Taken From The Previous Years Isc Aissce Hssce Various States Boards Roorke Qns Ncert Text From The Rate Of Increase Of Thickness Of Ice On A Lake

1. Calculate the time in which a layer of ice 6 cm thick, on the surface of a pond will increase in thickness by 2 mm. Temperature of the surrounding air $= -20^{\circ}\text{C}, L = 333\text{KJ kg}^{-1}$ Conductivity of ice =0.08cal s−1cm−1∘C−1..

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2. The thickness of ice on a Jake is 6 cm and the temperature of air is $-10^{\circ}C$. At what rate is the thickness of ice increasing ? Thermal conductivity of ice $= 2\text{Wm}^{-1}\text{K}^{-1}$. Density of ice $= 920\text{kg m}^3$, specific latent heat of ice $= 336\text{KJ kg}^{-1}$

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3. A pond has a layer of ice of thickness 0.25 m on its surface the temperature of the atmosphere is $10^\circ C$. Find out the time required to increase the thickness of the layer of ice 0.5mm. K of ice $= 2\text{Wm}^{-2}\text{K}^{-1}$.

Density of ice $= 900 \text{kg m}^{-3}$ latent heat of fusion of ice $= 336 \text{KJ kg}^{-1}$.

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Selected Problems Taken From The Previous Years Isc Aissce Hssce Various States Boards Roorke Qns Ncert Text From Thermal Resistance

1. The ratio of the thermal conductivities of two different materials is $1:2$. The thermal resistance of the rods of these materials having the same thickness are equal. Find the ratio of the length of rods.

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2. Calculate the thermal conductivity of the composite rod. The two rods A and B are made of two different materials of thermal conductivities K_1 and K_2 and are welded together.

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3. Three rods AB, BC and CD are connected as shown is Fig.11.23. They are of the same length and area of cross-section. The thermal resistance of AB is $15 \mathrm{KW}^{-1}$, BC is $10 \mathrm{KW}^{-1}$ an CD is $15 \mathrm{KW}^{-1}$. If the free ends are maintained at $100^\circ C$ and $0^\circ C$, calculate the rate of heat flowing through the combination.

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4. Four rods are joined and their free ends are maintained at 100°C and 30°C. What is the temperature of the junction C ? The thermal resistances of rods of AB and CD are 10 KW^{-1} each and BC and DE are 15 KW^{-1} each.

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5. A well insulated box is packed with ice at 0°C and kept in a room at a temperature of 30°C.

The lid of the box is made of a cardboard sheet of thickness 4 mm and area 100 cm^2. If the ice melts at the rate of 0.045 kg per hour, calculate the thermal conductivity of cardboard assuming that heat can enter the box only through the lid. [L.H. of fusion of ice $= 336\mathrm{KJ}/\mathrm{kg}$]

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6. A sheet of rubber and a sheet of cardboard, each 5 mm thick are pressed together and their outer faces are maintained respectively at 0°C and 18°C. If the thermal conductivities of rubber and cardboard are respectively 0.13 and $0.05 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$. find the quantity of heat which flows in one hour across a piece of composite sheer if area is $100 \mathrm{cm}^{-2}$.

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7. Calculate the rate of loss from a room through a glass window of area $1.5 m^2$ and thickness 2.5×10^{-3} m, when the temperature of the room is $25^\circ C$ and that of the air outside is $10^\circ C$. Assume that the inner glass surface is at the room temperature. [Thermal conductivity of glass $= 1.2 \mathrm{Wm}^{-1} \mathrm{K}^{-1}$]

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Selected Problems Taken From The Previous Years Isc Aissce Hssce Various States Boards Roorke Qns Ncert Text From Experiment To Determine K

1. In an experiment to find the thermal conductivity of rubber, a tube of length 10 cm with external radius 0.5 cm and internal radius 0.3 cm is immersed in 0.28 g of water at 30°C contained in a copper calorimeter of mass 0.20 kg and specific heat capacity $385 \mathrm{JKg}^{-1}\mathrm{K}^{-1}$. Through the tube, steam is passed for 10 minutes and the final maximum temperature of water and calorimeter is $42^\circ C$. Calculate the thermal conductivity of rubber. Specific heat capacity of water $= 4200 \mathrm{JKg}^{-1}\mathrm{K}^{-1}$.

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2. In an experiment to find the thermal conductivity of rubber, a tube of length 10 cm with external radius 0.5 cm and internal radius 0.3 cm is immersed in 0.28 g of water at 30ºC contained in a copper calorimeter of mass 0.20 kg and specific heat capacity $385 \mathrm{JKg}^{-1} \mathrm{K}^{-1}$. Through the tube, steam is passed for 10 minutes and the final maximum temperature of water and calorimeter is $42^{\circ} C$. Calculate the thermal conductivity of rubber.

Specific heat capacity of water $= 4200 \text{JKg}^{-1} \text{K}^{-1}$.

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